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ABSTRACT

This handbook presents an organized set of descriptive information on numerically controlled operational devices. The information is intended for those involved in industry and technical education and to contribute to the knowledge of numerical control technology. It is also intended for supervisors, manufacturers, machine operators, and others who do not have extensive technical background in numerical control. (Author/SA)

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HANDBOOK ON

NUMERICALLY CONTROLLED OPERATIONAL DEVICES

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
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PREFACE

The purpose of this handbook is to present an organized body of descriptive information concerning numerically controlled operational devices. It was determined that such information would be of value to industry and technical education as well as to the development of general understandings about numerical control technology.

This reference is addressed to educators, manufacturers, supervisors, machine operators, and others who do not have an extensive technical background in numerical control. It is intended as a means of increasing knowledge and understanding of numerical control applications to various equipment.

Clifton P. Campbell

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SECTION I

INTRODUCTION

A measure of man's technological progress has been his ability to use tools. The level of sophistication of these tools serves as an index of his manufacturing capability. Numerical control evolved from a continuum of inventions and technological innovations. Technological progress has lead numerical control into the domain of "cybernation," where the limitations of the human operator no longer impose serious constraints upon the performance of manufacturing tools. Holmes, a numerical control planning specialist, stated that:

> Progressive steps toward fully automatic production have involved the upgrading of the tools that man uses in manufacturing from simple hand tools to manual control of machines, semi-automatic machines, fully automatic machines, and computerized production.[1]

Numerical control, a fundamental manufacturing concept, has been defined by the Electronic Industries Association, as "a system in which actions are controlled by the direct insertion of numerical data at some point. The system must automatically interpret at least some portion of this data."[2] Numerical control means that a program of machine control commands, comprised of organized and documented symbolic codes, recorded on a suitable media, direct some or all of the operations of a specific machine.

The words "numerical control" and "numerically controlled" are commonly abbreviated N/C. This symbol appears frequently throughout this report.

Commercial production of numerical control (N/C) machines began in the United States in 1954.[3] Since that time, machine builders have proposed the concept of N/C for drafting, industrial production, inspection and testing, and other manufacturing operations. Application is practicable from product design to the manufacture and inspection of the finished part.

With this manufacturing concept of automatic machines under symbolic control has come the era of direct communication with machines. Machines are characterized as an extension of man's hand, but with numerical control they encompass the extension of man's mind. This was supported by Thornhill when he commented:

> Numerical control is as much a way of thinking as it is a way of doing. In fact, it could be considered a way of organizing and analyzing manufacturing. Herein lies an entire new philosophy of drafting, design, and production, as well as a new technology of machine control.[4]

The use of numerical control has relieved man from the necessity of functioning as a control element. Drudgery inherent in the control function has been assigned to a machine. Man can now concentrate on tasks more suited to his abilities.

Developments in machine tool technology, prior to N/C, emphasized increased power, speed, specialization and

automation. The primary difference between automated machines and numerical control is the method of supplying input data and obtaining feedback signals. Howe stated that:

> The characteristic which differentiates N/C from automation is the feature of programmed instructions. In N/C, the program replaces tooling, fixturing, automatic sequencing, etc., which, in automation are required to guide and control the relative motion between the tool and workpiece.[5]

Numerical control applied to automatic machine operation, is achieved by means of instructions expressed in code. Machine control commands, comprised of organized and documented symbolic codes, are prepared in advance and recorded on a suitable media. These coded instructions represent a fixed logic and can control some or all of the operations of a specific machine. Thus, numerical control is a method of controlling machine processes. The instructions for control are recorded on some media that can be used a number of subsequent times to produce identical functions.

The input media, containing coded instructions, is placed on a machine control unit which consists of a system of electronic interpreting devices. These devices, when activated, control the N/C machine through the previously programmed operations with little or no human intervention.

Cost, accuracy and efficiency are factors influencing the rapid growth of numerically controlled manufacturing processes. The impact of N/C on the metalworking industry was described by Hatschek when he wrote:

> It /N/C/ promises to have the same revolutionary effect upon the metalworking industry that the automobile has had on the national economy. Since the horse and buggy were replaced by motor cars, life has not been the same. Life in metalworking already is taking on a new aspect as a result of the introduction of N/C.[6]

Since its commercial introduction, applied research and development have continued to advance numerical control technology. In particular, the reliability of control components has been increased, special systems for a variety of specific machine applications have been devised, and a wide range of competing systems featuring varying combinations of electronic, electrical, hydraulic, optical, pneumatic, and mechanical control devices have become available, replacing earlier hand cranks, gear trains, cams and levers. These refinements in N/C hardware, and their integration with the computer have changed the basic concepts of manufacturing. American industrial technology has advanced to the threshold of a new industrial revolution.

SECTION II

OPERATIONAL DEVICES

The scope of N/C applications has tended to be limited only by economic feasibility and man's ingenuity. Thus, it can be applied to any operation that requires controlled motion.

Design and Drafting

Numerically controlled drafting and plotting machines have many uses. Among them are: preparation of preliminary design drawings from mathematical descriptions; verification of tool and cutting path data on machine control input media; contour mapping; layout of printed circuit artwork masters and inspection templates; architectural drafting; automatic drafting of complex three-dimensional shapes such as aerodynamic surfaces, automobile bodies, ship hull forms, tire treads, impellers, and turbine blades.[7] These machines are also used to prepare various graphical forms such as graphs and charts from numerical data for analysis and verification.

Numerically controlled drafting machines. A complete computer-aided drafting system consists of a digital computer and N/C drafting machine. Drafting machines are connected directly to a computer or are off-line and use computer output as a control media. The off-line mode of operation is normally used because of the time disparity between the

electronic speed of the computer and the mechanical speed of the drafting machine. Initially, mathematical descriptions in numerical form are prepared by a part programmer and processed through a computer, resulting in coordinate data encoded on magnetic tape, punched cards, or punched tape. This output constitutes a set of detailed instructions which are used by the N/C drafting machine to produce a graphical presentation.[8] Input media is fed through the reading device of an N/C drafting machine and processed by the control unit. Control output signals drive a pen, stylus, or optical exposure head on the drafting machine to produce an accurate, quality drawing, on various materials, at speeds greater than those obtainable manually. All types of lines and forms can be drawn in a number of widths and colors. The N/C drafting machine can provide mirror image or reverse drawings, scale up or down, rotate, translate, and project data to any desired view.[9] Some models have full alphabetic and numeric printing capabilities. A number of N/C drafting machines have digitizing capabilities for the acquisition of coordinate data to define points, lines, and curves on existing drawings or patterns.

A representative example of an N/C drafting machine is pictured in Figure 1. The Series 600 control unit and Model 22 graphic display table are manufactured by the Gerber Scientific Instrument Company. This is a solid state continuous path system with buffer storage, a sequence number display, and a linear interpolator. It can draw at the rate of 150 inches per minute

with an accuracy of ±0.007 inch and can scale the size of a graphic presentation from half size to sixteen times size.[10] A drawing head, with an optical turret for automatic selection from six different drawing tools is positioned by an X and Y carriage which executes the commands of the control unit. Positioning along the X axis is achieved by a rack and pinion gear train adjacent to the precision table ways. The Y carriage, basic tool holder, is positioned along the X carriage by a helical lead screw. Digital stepping motors are used in the basic drive system of both axes.

Numerically controlled plotting machines. Plotting machines are similar in concept and operation to N/C drafting machines. The differences are primarily in the degree of accuracy and the quality of the graphical presentation that can be produced. The plotter is an X-Y positioning system which can plot computer output as it is being generated or operate off-line using computer output as a control media. When the plotter is used on-line, the plot data and control commands are supplied through interface electronics. In the off-line mode of operation, which is normally used, magnetic tape is played back on the control unit which supplies the X and Y axis drive signals, mode selection signals, and Z axis commands to the plotter.[11] Many N/C plotters have mirror image capability and drawing scale flexibility. They are available in flatbed and drum models.

A representative example of an N/C plotting machine is illustrated in Figure 2. The Calcomp Model 565 drum plotter is

manufactured by California Computer Products, Incorporated. It has an X-Y axis plotting speed of 18,000 steps per minute and a Z axis (pen) speed of 600 operations per minute. Bi-directional stepping motors are used to position the X and Y axes. Plotting is regulated by the movements of a pen relative to the surface of the paper, with each input pulse causing a step of either 0.01 or 0.005 inch. The X axis deflection is produced by the motion of a rotating drum and the Y axis deflection is produced by the motion of a pen carriage. Command signals raise and lower the liquid ink or ballpoint pen from the surface of the paper. All plotting, discrete points, continuous lines, or symbols, is accomplished by the stepping action of the drum and pen carriage. Paper alignment is maintained by sprockets on the drum. Various types of roll stock paper and mylar, either twelve or thirty-one inches wide, and blank or with grid markings, are used. Manual controls for positioning the drum and pen carriage, and for raising and lowering the pen are provided. Controls to initiate any of three modes of operation, search, single plot, and multiple plot, in addition to miscellaneous tape modes such as fast, forward, and rewind, are located on the front panel of the control unit.[12]

Production Equipment

Numerical control has been adopted more extensively for use by production equipment than by any other application. The general acceptance of this technological innovation came about as a result of its inherent qualities of increased accuracy,

increased production and interchangeability of the end product.[13]

Drilling machines. A large number and variety of N/C drilling machines are marketed. The key advantage of N/C drilling is the elimination of the high costs associated with positioning jigs and fixtures.[14] Numerically controlled drilling machines are available in a variety of models, from two-axis machines with single spindles, to three-axis machines with automatic tool changers or turrets. Most drilling machines have some milling capability.

Typical of the smaller types of special purpose N/C drilling machines are printed circuit board drills. These machines are equipped with single or multiple stations. A drilling machine designed for precision drilling of a large number of holes in printed circuit boards or other flat stock is illustrated in Figure 3. This machine, manufactured by the Edlund Division of the Monarch Machine Tool Company, has four stations, each with a cluster of four drill spindles with independent feed and speed control. The positioning table is mounted on the base along with a column which holds a vertically adjusted bracket fitted with independent air feed units of four groups of four units each. The drills are automatically selected by programmed information and the positioning speed is 200 inches per minute.[15]

A typical general purpose, two-axis N/C drilling machine is the Moog Model 83-200. This representative example of a point-to-point vertical drilling machine capable of limited

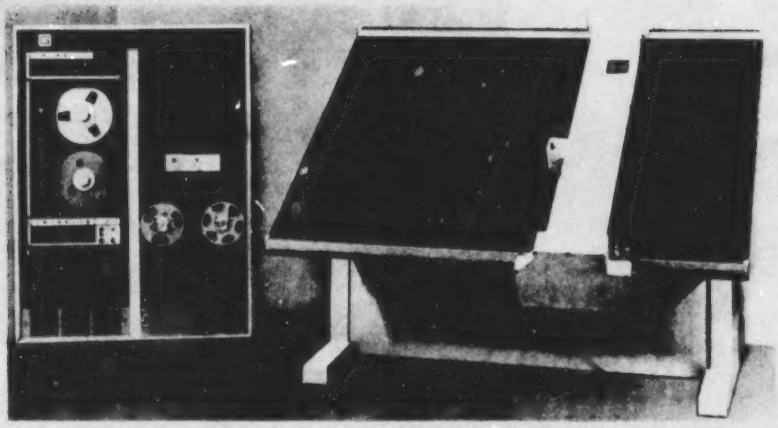

Figure 1. Drafting Machine (Courtesy of Gerber Scientific Instrument Company)

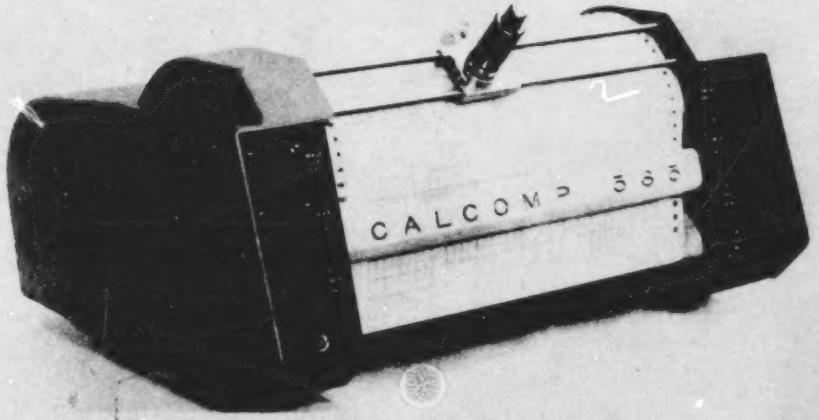

Figure 2. Plotting Machine (Courtesy of California Computer Products, Inc.)

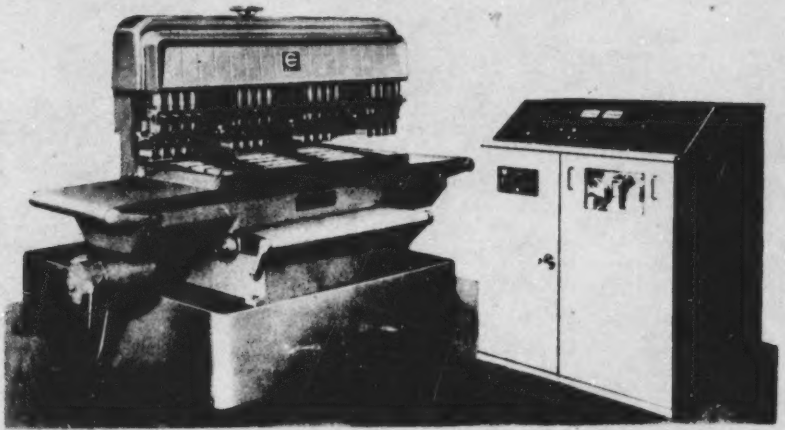

Figure 3. Printed Circuit Board Drill (Courtesy of Edlund Division of Monarch Machine Tool Company)

straight line milling along the X and Y axes is illustrated in Figure 4. It has a single spindle with manual or mechanical Z axis control and manual tool changing. The pneumatic-hydraulic positioning control system positions at the rate of 180 to 200 inches per minute with ±0.001 inch accuracy. Control and positioning components used in this machine are manufactured by Moog, Incorporated, and are fitted at their factory to a specially designed and built Bridgeport vertical mill.[16] The machine control unit (MCU), attached to the head of the machine tool, contains a pneumatic block reading device, manual input dials, and a mechanical sequence counter.

Another successful application of N/C drilling is turret drilling. The turret head functions to some degree as an automatic tool changer. The number of tools used - six, eight, or ten - varies with the design of the turret. Numerically controlled turret drills are capable of cycling automatically, selecting tools, and positioning the table and carriage in the X and Y direction. Both two- and three-axis control systems are used. A typical N/C turret drill is illustrated in Figure 5. This Burgmaster Model 3 BHT-3, manufactured by the Burgmaster Division of Houdaille Industries, has double housing planer type construction which provides maximum strength and precision for large workpieces. The machine tool has an eight spindle turret and is equipped with a General Electric Mark Century MCU. It has a three-axis positioning control, and can perform milling and boring operations, in addition to drilling.[17]

Milling machines. There are various kinds of milling

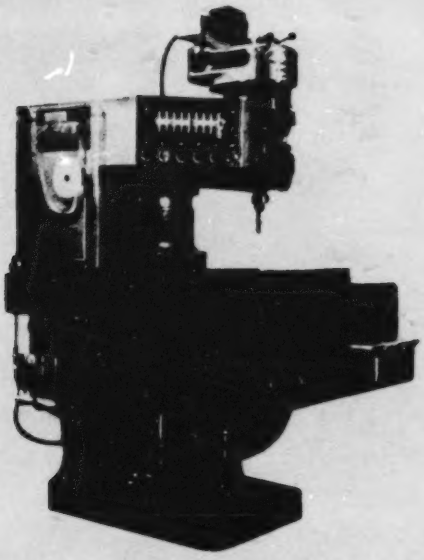

Figure 4. Two-axis Drilling Machine (Courtesy of Moog, Incorporated)

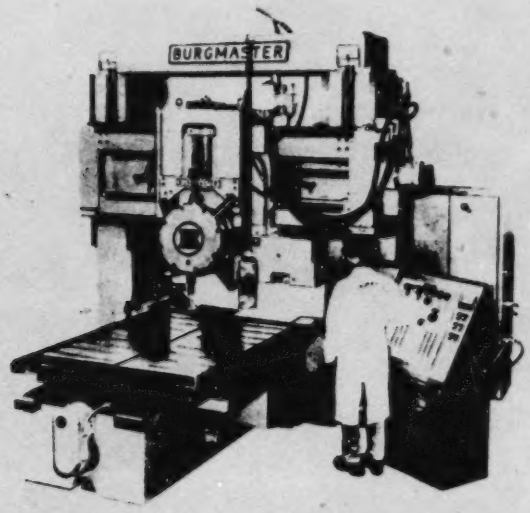

Figure 5. Turret Drill (Courtesy of Burgmaster Division of Houdaille Industries)

machines, such as die sinkers, contouring and profiling machines, skin and spar mills, as well as general purpose knee and bed models. Milling machines are generally classified as horizontal or vertical types.[18]

A representative N/C horizontal milling machine is pictured in Figure 6. This two-axis Cincinnati milling machine, with an Acramatic 220 solid state point-to-point MCU, is manufactured by the Cincinnati Milacron Company. The MCU is equipped with a tally tape reading device, manual input decade switches, and sequence number and position displays. In addition, it has full range zero shift capability. A 33¼ by 48 inch work table handles workpieces as heavy as 5500 pounds at milling feedrates of two to thirty inches per minute. The table is positioned by a 7½ horsepower hydraulic servo motor driving a ball nut lead screw. Third axis (Z) control is facilitated through manually set cams. This N/C machine tool is also capable of drilling, tapping, and boring operations.[19]

A two-axis Cincinnati vertical N/C milling machine with an Acramatic 220 point-to-point MCU is illustrated in Figure 7. The machine control unit and other components are identical to those used in the horizontal milling machine. A twenty by forty inch work table which handles workpieces as heavy as 1500 pounds is positioned by a five horsepower hydraulic servo motor. In addition to milling, operations such as drilling, tapping, and boring can be performed on this machine.

Boring machines. Numerically controlled boring machines, with from two to eight axes of movement, can be equipped with

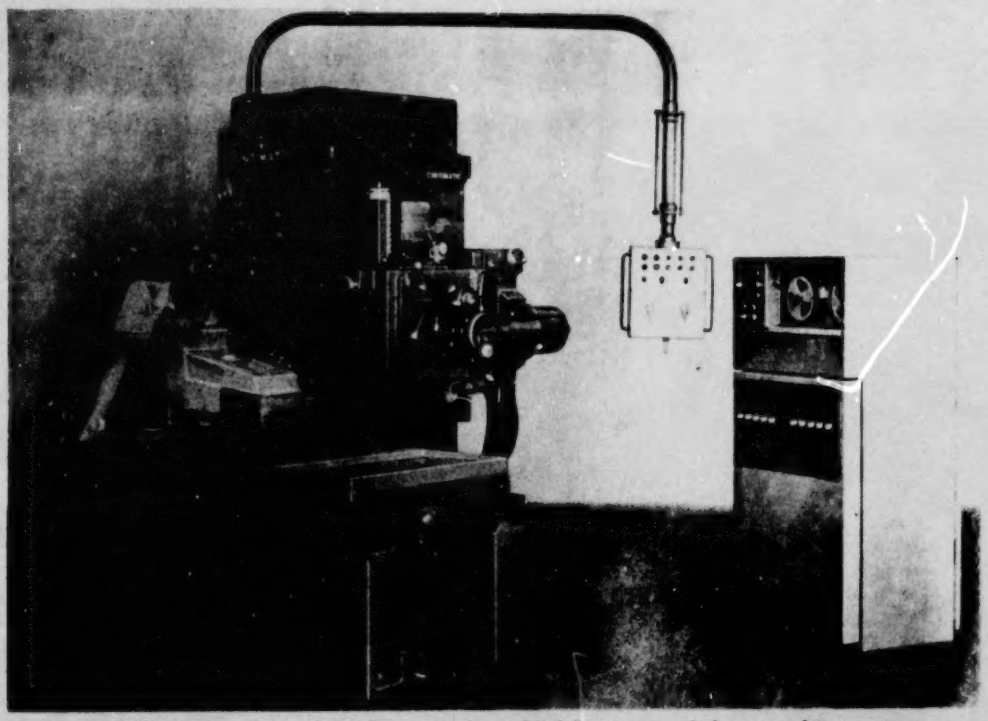

Figure 6. Horizontal Milling Machine (Courtesy of Cincinnati Milacron Company)

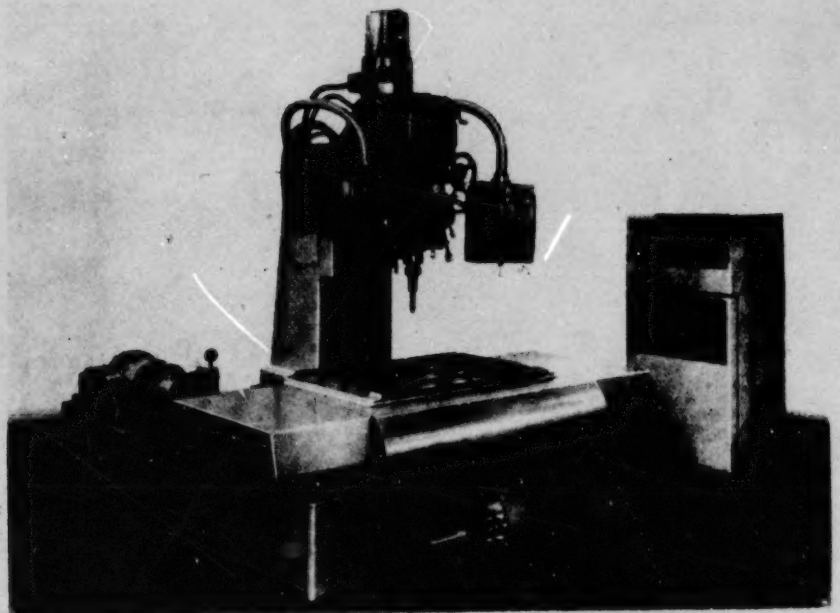

Figure 7. Vertical Milling Machine (Courtesy of Cincinnati Milacron Company)

point-to-point or continuous path control systems. They are classified as horizontal or vertical machines.[20]

In horizontal boring, a horizontal spindle and cutting tool remove metal by rotation of the spindle. The workpiece is located on a table which can position in the X and Y directions, and in some cases a rotary table is used for 360 degree positioning. This type machine can be used to bore, mill, and drill. A horizontal boring machine manufactured by the Lucas Machine Division of The New Britain Machine Company is illustrated in Figure 8. The Lucas Model 542B120 is equipped with a three-axis continuous path machine control unit. A rotary transducer is mounted directly on the end of the lead screw, which is driven by a hydraulic motor and servovalve.[21]

A vertical boring machine consists of a large rotating table to which a workpiece is attached. An adjustable rail containing the cross rail head or heads is mounted on columns. The head(s) move in or out on the rail. In addition to boring, turning and other operations similar to those performed by vertical turret lathes can be performed. A single head vertical boring machine manufactured by the G. A. Gray Company is illustrated in Figure 9. This machine has an integrated circuit two-axis continuous path MCU with linear and circular interpolation.[22] Commands from the MCU determine the speed of a rotating table driven by helical and spiral bevel gears powered by a DC motor. A five tool indexing turret attached to the end of a ram can be extended into deep holes.

Turning machines. Some of the different types of N/C

turning machines or lathes are the horizontal turret lathe, vertical turret lathe, engine lathe, and chucking lathe.

The horizontal turret lathe (bar lathe) is generally used for multiple cuts such as drilling, boring, reaming, tapping, facing, turning, and parting off detail parts from random length metal bars. A representative N/C horizontal turret lathe is shown in Figure 10. This is a Jones and Lamson Model 4518-NCTL three-axis turret lathe with a General Electric Mark Century MCU, manufactured by Jones and Lamson, Division of Waterbury Farrel Company. The MCU has facilities for manual data input and manual operation, as well as tape control for turning. The turret lathe carriage and cross slide respond to linear and circular interpolation of programmed information for continuous path turning. At the same time, the saddle responds to end point positions for the third axis of motion. Each slide is positioned by an electric or hydraulic motor driving a ball nut lead screw. A rotary resolver, driven by the lead screw, provides feedback to the closed loop system.[23]

The vertical turret lathe is used for multiple cuts such as facing, turning, and/or boring of parts too large to be machined on standard-size horizontal lathes. The vertical Giddings and Lewis turret lathe illustrated in Figure 11 is equipped with a four-axis N/C point-to-point control system. Two of the four axes control the ram head while the other two control the side head. Commands from the MCU index the turret and determine table speeds. The work table is driven by a variable speed DC motor with a high and low gear. When equipped

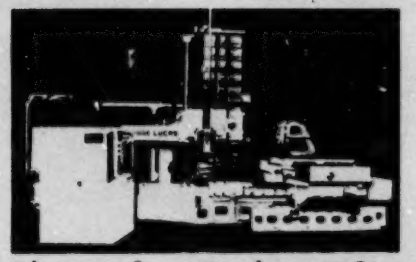

Figure 8. Horizontal Boring Machine (Courtesy of Lucas Machine Division of The New Britain Machine Company)

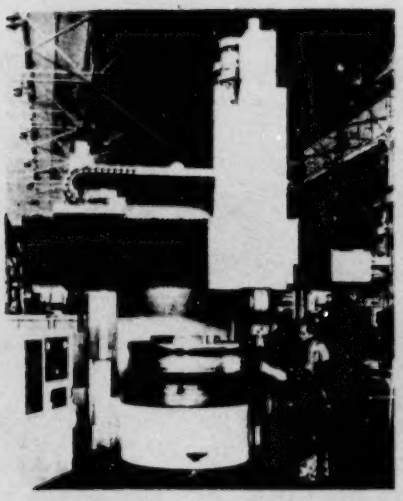

Figure 9. Vertical Boring Machine (Courtesy of G. A. Gray Company)

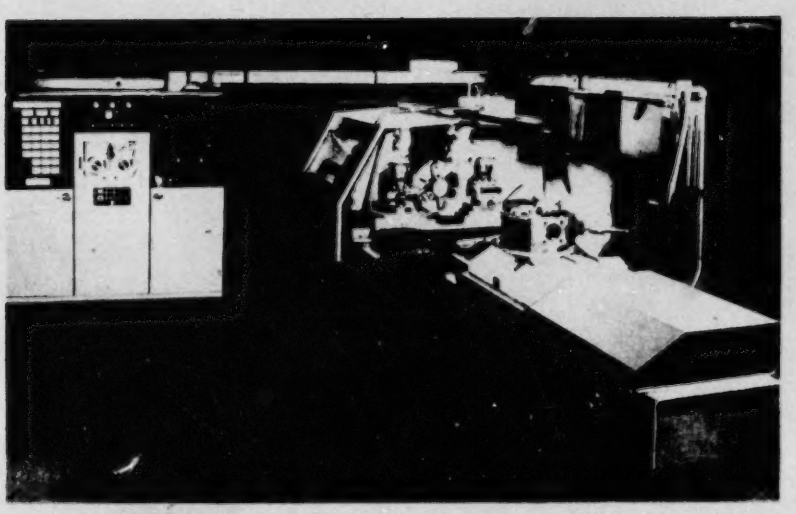

Figure 10. Horizontal Turret Lathe (Courtesy of Jones and Lamson, Division of Waterbury Farrel -- A Textron Company)

with a continuous path control system, this machine uses an Inductosyn linear feedback device for each axis under control of the MCU.

The engine lathe is usually used for turning parts between centers, or for facing, turning, boring, or single point thread chasing on workpieces that can be held in a chuck or collet. A representative N/C engine lathe is illustrated in Figure 12. This is an American Model 3220 two-axis N/C engine lathe with a General Electric continuous path MCU. It is equipped with resolvers for shifting the zero reference of each axis. An operator's control station mounted on wheels facilitates locating push-button controls near the carriage of the lathe or in any other convenient place. DC motors operating from silicon-controlled rectifiers drive ball nut lead screws for feed control.[24]

The N/C chucking lathe is used for turning, threading, facing, drilling, boring, reaming, and other operations. A representative example of an N/C chucking lathe is the Monarch Pathfinder, manufactured by the Monarch Machine Tool Company. It is equipped with a General Electric Mark Century solid state 100S machine control unit. The chucking lathe has a hexagonal turret and two tape-actuated auxiliary slides. Two-axis continuous path control of the turret with circular interpolation provides the capacity for generating almost any part configuration within the size limitations of the machine.[25]

Machining centers. Thus far in the description of N/C production equipment, drilling, milling, boring, and turning

machines have been described. Some models of these machines, with automatic tool changers, might fall into the machining center classification, when they are capable of performing different operations, such as drilling, milling, boring, tapping, and reaming. Full automation is one characteristic of a machining center; all system functions are numerically controlled.[26] Machining centers are manufactured in different configurations based on classic combinations of beds, columns, saddles, and tables. Optional features of machining centers include multiple spindle heads, shuttle pallet systems, dual tape readers, and as many as five axes of machine control. A representative N/C machining center is illustrated in Figure 13. This Kearney and Trecker Milwaukee-Matic unit, manufactured by Kearney and Trecker Corporation, is equipped with a point-to-point and continuous path control system which provides positioning and two-axis (X and Y) contouring. It has random tool selection and changing. A pallet shuttle, for the reciprocal machining of a workpiece, automatically transfers a pallet with completed part off the index table and presents another to the machining station.[27] This reduces nonproductive time associated with part loading and unloading.

A maximum of sixty preset tools can be loaded, at random, in a chain type tool storage magazine, with one additional in the spindle. The tool storage magazine rotates automatically on command of the MCU and exchanges the preselected tool in the spindle.

Grinding machines. Grinding is a metalcutting process

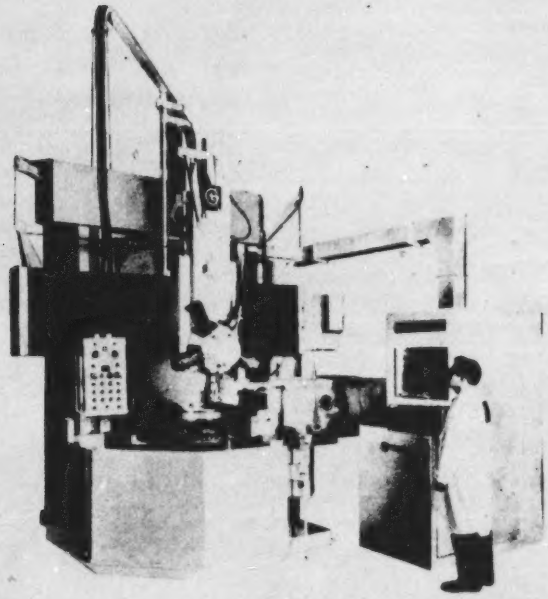

Figure 11. Vertical Turret Lathe (Courtesy of Giddings and Lewis Machine Tool Company)

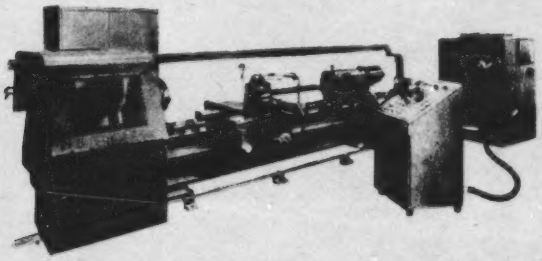

Figure 12. Engine Lathe (Courtesy of The American Tool Works)

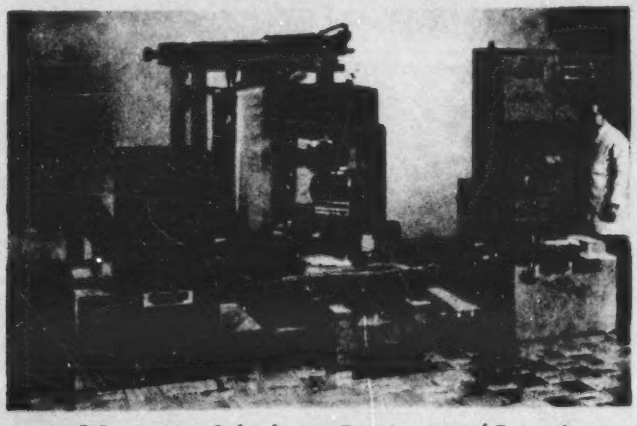

Figure 13. Machining Center (Courtesy of Kearney and Trecker Corporation)

accomplished by the controlled rotation of an abrasive wheel against a workpiece. Numerical control is applied to grinding because of its ability to control contours and provide close tolerances.[28] A representative example of an N/C contour grinder is the Numera-Tool, manufactured by the Ex-Cell-O Corporation. This three-axis vertical contour grinder is equipped with a Bendix Dynapath Model 1503 continuous path machine control unit. The integrated circuit MCU is designed to accept computer interface or punched tape input. The machine tool has a twenty-four inch diameter turntable and a vertical worm gear driven servo controlled spindle. A motorized spindle, mounted to a horizontal servo controlled cross slide and affixed to the vertical servo controlled slide, powers the grinding wheel. Maximum traverse rate in the linear axes is 200 inches per minute, and the maximum rotary speed of the workpiece spindle is thirty revolutions per minute.[29]

Punching and notching machines. Punching or piercing produces a hole in sheet or thin plate material. Numerical control makes it possible to select any location, size, and shape of hole. Two basic types of N/C presses which provide single stroke piercing have been developed. One is the single station type where tools are manually changed during the cycle, and the other is a turret type which automatically indexes tools into position.[30]

Single station machines hold one punch and die at a time. Numerical control is used to position a workpiece in relation to the punch and die, for punching holes, notching,

blanking, nibbling, and forming. A representative single station punching and notching machine is pictured in Figure 14. This Strippit Fabramatic Model 30/30 two-axis machine, manufactured by Strippit, Division of Houdaille Industries, facilitates short run production of large complex workpieces. Round or shaped holes, notches, and cutouts of practically unlimited variety are punched automatically. Although normal operation is automatic, semi-automatic and manual modes are provided to verify machine control tapes, check performance, or manually operate the machine.[31]

Turret type punch presses can process a completed workpiece in a single setup. A representative example of a turret type punching and notching machine is illustrated in Figure 15. This two-axis Wiedematic Model A-30 turret punch press, manufactured by the Wiedemann Division of Warner and Swasey Company, is equipped with a General Electric Mark Century point-to-point MCU. Power is provided by rotary hydraulic motors with closed loop servo-valve control and resolver feedback. Both the carriage and cross slide are driven by rack and pinion gears. The thirty station punch turret can be rotated in either direction. All positioning functions, as well as turret indexing, occur simultaneously. In addition to punching round, square, or a variety of oval shaped holes, the machine notches, nibbles, pierces, and centerpunches.

Tube bending machines. Operation of the N/C tube bender consists of positioning a tube, solid bar or wire, and then bending it to the desired angle. Improved accuracy, additional

versatility, and automatic operation resulting in decreased production costs, inspection time, and scrap, are a few of the advantages of the N/C tube bending machines.[32] Tubes are bent into a variety of configurations and used by aerospace, aircraft, machine tool, appliance, automotive, and other industries. N/C tube benders are used for bending boiler and heat exchanger tubes. They are particularly useful where relatively few tubes of any one shape are required, although the individual part might have many bends and must match precisely with its mating members. A representative N/C tube bending machine is illustrated in Figure 16. This Pines Numri-Form Model NC-2 N/C tube bending machine and Cybermat integrated circuit MCU are manufactured by the Teledyne Pines Company. The machine control unit is a point-to-point three-axis system. An electronic memory unit in the MCU stores data for as many as twenty-four bends. Manual and punched tape input are used. Punched tape extends the use to workpieces requiring more than twenty-four bends and permits accurate duplicates or original runs.[33] A feature of this machine is its ability to sense and measure the degree of material springback in a bend, and then overbend to achieve the desired angle.

Flame cutting machines. Numerically controlled flame cutting machines are used to cut plate stock for large fabrications, such as earth moving equipment, steel structures, bridges, ship hulls, tanks, and others. This equipment eliminates the need for templates, scale drawings, and reliance on a skilled operator to control flame cutting processes.

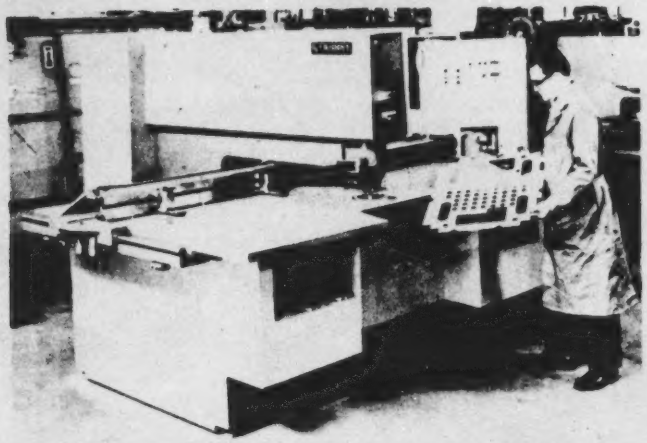

Figure 14. Single Station Punching and Notching Machine (Courtesy of Strippit, Division of Houdaille Industries)

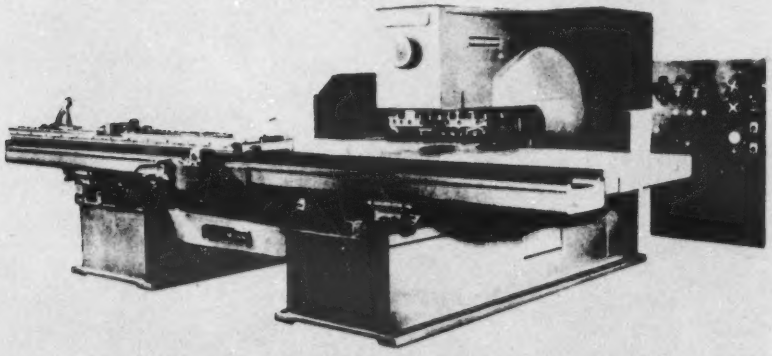

Figure 15. Turret Type Punching and Notching Machine (Courtesy of Wiedemann Division of Warner and Swasey Company)

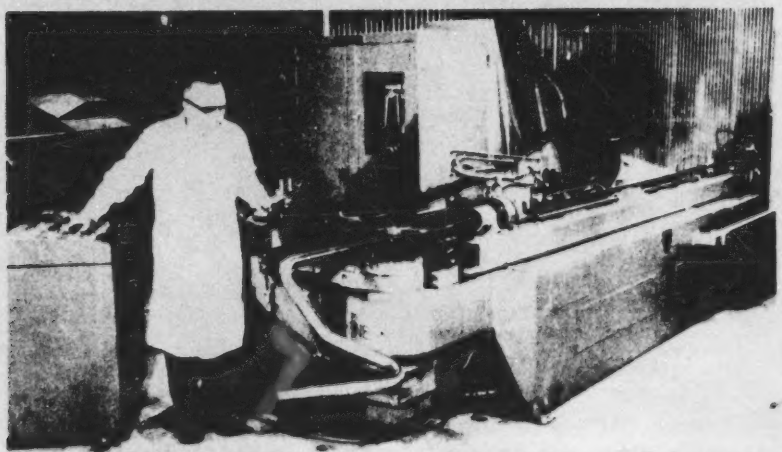

Figure 16. Tube Bending Machine (Courtesy of Teledyne Pines Company)

Continuous path control directs marking, punching, and scribing for layout purposes, in addition to flame and plasma arc piercing and contour cutting in steel plate.[34] An example of a bridge type N/C flame cutting machine is pictured in Figure 17. The Tape-O-Graph unit is manufactured by the Air Reduction Company, with a General Electric three-axis Mark Century MCU. The Tape-O-Graph performs plate marking, straight line and contour cutting, ripping and squaring, plate edge preparation, and contour beveling, as well as mirror image and dissimilar contour cutting. Both flame and plasma cutting are possible. A coordinated drive system, powered by servo motors and a rack and pinion drive, permits longitudinal and traverse motions to position simultaneously.[35]

Large fabrications such as ship hulls, bridges, and tanks are designed with the aid of a computer which performs fairing of lines between points. The computer output is a machine control tape used to operate the flame cutting machine which produces smooth and accurate curved surfaces.

Welding machines. Numerically controlled welding is the result of demands for improved standards of welding quality for aerospace activities.[36] In addition to positioning the workpiece to be welded, factors involving the welding cycle are automatically controlled. A Sciaky five-axis N/C fusion welding machine is illustrated in Figure 18. This machine consists of five main elements.

One element is a traveling column ram manipulator which carries the welding head. A second element is the weld

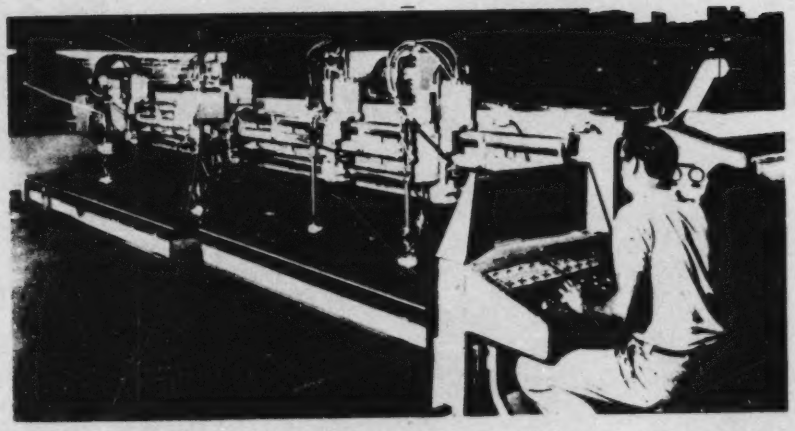

Figure 17. Flame Cutting Machine (Courtesy of Air Reduction Company)

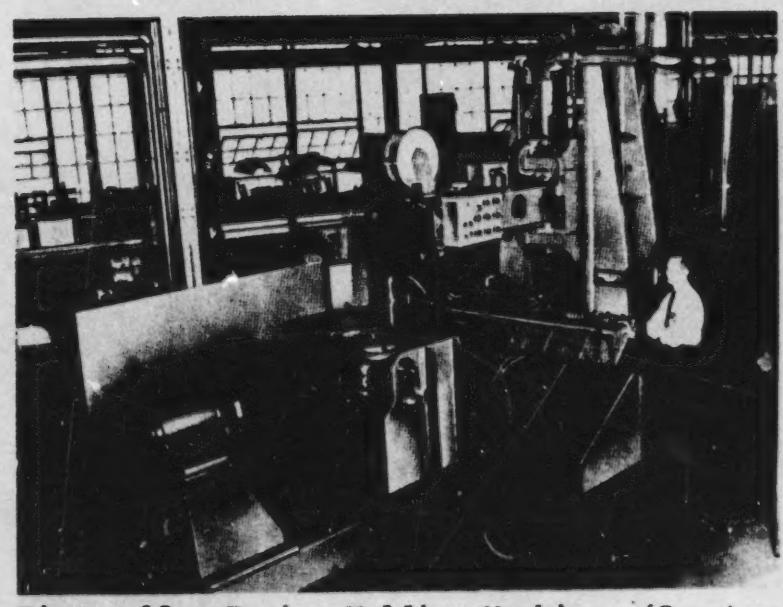

Figure 18. Fusion Welding Machine (Courtesy of Sciaky Brothers, Inc.)

positioner and tailstock unit which holds the workpiece to be welded. A third element consists of the fusion welding equipment, which is under the control of the MCU. The fourth element is a servo system, which employs static solid state power amplifiers, to control the current to DC drive motors. The fifth element consists of a Bendix solid state Dynapath five-axis continuous path MCU with manual and punched tape input. Machine movements in five axes and the temperature of the welding arc are controlled simultaneously by the MCU with repeatable accuracy.[37]

Filament winding machines. Filament winding is the technique of spinning strands of tough fibers to a desired shape over a mandrel and impregnating them with a resin to form a vessel. Taking maximum advantage of the high tensile strength of a filament permits strong, lightweight construction for a variety of vessel shapes, such as rocket motor cases.[38] Numerically controlled filament winding machines provide filament path and tension control during fabrication so that the strength of the resulting vessel coincides with directional strength requirements. A representative N/C filament winding machine is pictured in Figure 19. The three-axis machine is manufactured by the Rohr Corporation and equipped with a Bunker-Ramo MCU. The machine can wind pressure vessels as much as eight feet in diameter and eighteen feet long.

Component insertion machines. Numerically controlled component insertion machines are used in the manufacture of printed circuit boards. A component insertion machine inserts,

cuts, and clinches the component leads, assuring proper circuit contact and improved solderability. A variety of means for supplying components to the machine are used. One method is to use an N/C device for selecting, and then stringing, different electrical components in proper order.[39] A Universal Model 2521 automatic axial lead component sequencer, manufactured by the Universal Instruments Corporation, is illustrated in Figure 20. After a reel of components has been prepared on equipment of this type, it is loaded onto a component insertion machine which inserts the components into a circuit board. A representative component insertion machine is illustrated in Figure 21. This machine is manufactured by the Universal Instruments Corporation and is equipped with a General Electric Mark Century MCU. It positions two circuit boards simultaneously, inserts the electronic component leads into the proper holes, then cuts and clinches them.

Wire processing machines. Machines controlled by punched card or punched tape input media provide an accurate means of processing different sizes and types of wire from reels. Numerically controlled wire processing machines measure, mark, cut, strip, and coil sections of wire so that they are ready for use.[40] A point-to-point Datex Model WPM-100 wire processing machine, manufactured by the Datex Corporation, is illustrated in Figure 22. This machine is approximately twenty feet long and is equipped with a machine control unit capable of automatic, semi-automatic, or manual control.

Another process is wire wrapping, by which insulated

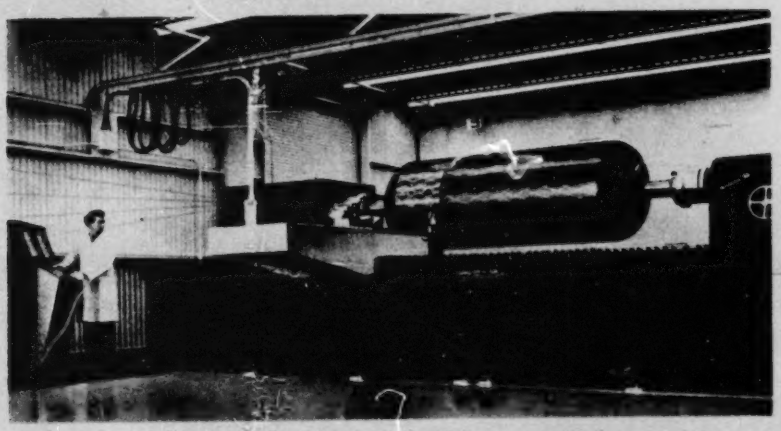

Figure 19. Filament Winding Machine (Courtesy of Rohr Corporation)

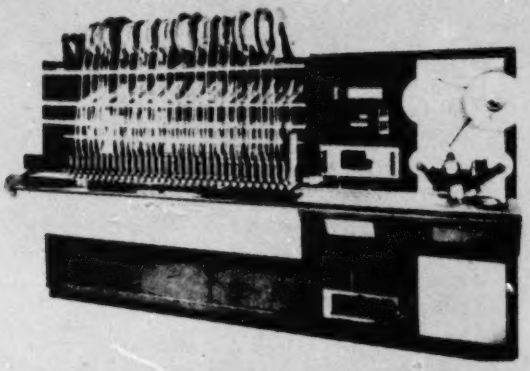

Figure 20. Component Sequencing Machine (Courtesy of Universal Instruments Corporation)

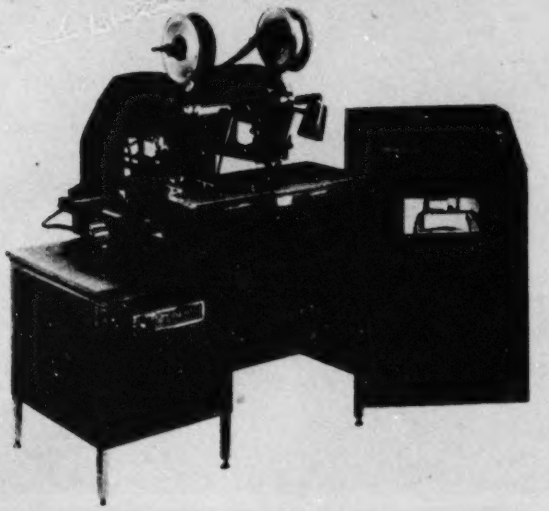

Figure 21. Component Insertion Machine (Courtesy of Universal Instruments Corporation)

conductor wire is automatically fastened to terminals with solderless wrapped connections. Electronic or electrical assemblies which have a modular terminal arrangement can be wired by this equipment. A representative N/C wire wrapping machine is pictured in Figure 23. This Gardner Denver Model 14F wire wrap machine was manufactured by the Gardner Denver Company. It strips insulation from one end of a wire fed from a barrel or bulk spool, wraps the end around a predetermined terminal, lays the wire along a preselected path, cuts it to length, strips the other end, and wraps that end around a second terminal.[41] The machine consists of movable carriages containing wire wrapping tool assemblies and dressing fingers which are positioned at modular points to give the desired wire pattern. This machine is designed so that either punched card or punched tape input media can be used for automatic operation. Fault indicating circuits are provided to facilitate constant inspection of machine performance and output during operation. Errors in programming or operation are detected, thus decreasing panel inspection time and rework.[42]

Fabric cutting machines. Numerically controlled fabric cutting machines provide a unique system for automatic cutting of fabrics and fabric-like materials. This equipment combines the versatility of manual cutting machines, guided by an experienced cutter, and the accuracy of automatic die cutting. A representative N/C fabric cutting machine is illustrated in Figure 24. The Cincinnati fabric cutting machine and Acramatic IV machine control unit are manufactured by the Cincinnati

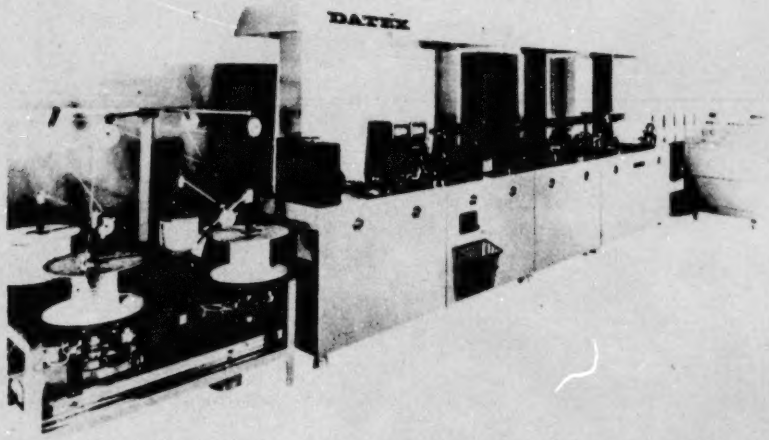

Figure 22. Wire Processing Machine (Courtesy of Datex Corporation)

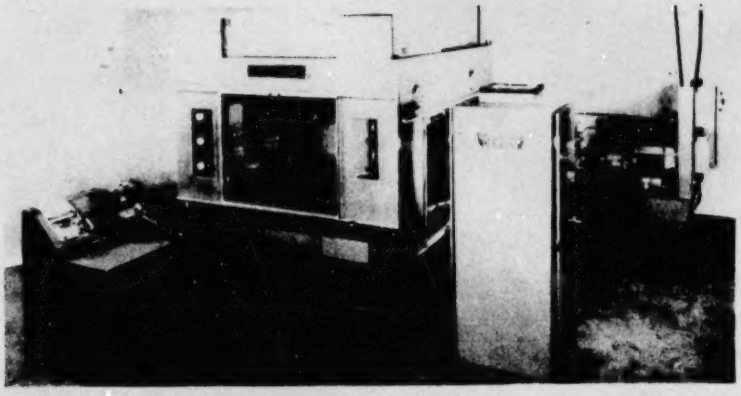

Figure 23. Wire Wrapping Machine (Courtesy of Gardner Denver Company)

Milacron Company. The MCU controls the feed rate and the positioning of the reciprocating blade and fabric. A machine table unit, on which layers of fabric are placed, consists of two separate synchronized endless conveyor belts driven at variable speeds. A bridge which supports a movable cutting head spans the machine table.[43] An adjustable holding device under and across the bridge contains two pairs of rollers spanned by a friction pressure belt to prevent the fabric from buckling. The carriage located under the table provides support for the cutting blade and is synchronized with the upper carriage to control the blade through the layers of fabric. A movable cutting head contains three electric motors. One motor ensures that the cutting edge of the blade is pointed into the cut, a second motor powers an automatic blade sharpener, and the third motor drives the reciprocating blade at 3600 motions per minute.[44]

Routers and shapers. Numerically controlled woodworking routers and shapers are designed to provide fast cutting with high spindle speeds and feed rates. A representative N/C woodworking router is pictured in Figure 25. This Ekstrom Carlson #444 Rout-O-Mill, equipped with a two-axis Bunker-Ramo machine control unit, is manufactured by Ekstrom, Carlson, and Company. All functions, such as point-to-point or continuous path cuts, spindle up or down, spindle start or stop, turret stop index to varying cutter depths, and mirror image, are controlled by the MCU. A twenty-four by seventy-two inch work table, mounted on four hardened and ground guide bars, holds a

workpiece, while a moving column and ram traverse the area. Ball nut lead screws, driven by hydraulic servomechanisms, position each motion from 0 to 400 inches per minute.[45]

Miscellaneous production equipment applications. The following machines are further examples of N/C applications in production equipment.

A numerically controlled screwdriver resulted from the coupling of an automatic screwdriver with a hopper feed and a point-to-point machine control unit. This assembly is manufactured by Dixon Automatic Tools. A holding fixture mounted on an X-Y table accommodates two workpieces. The depth motion, used to drive the screw, is manually set.[46]

One attempt at N/C riveting employs an automatic drilling and riveting machine to fabricate aircraft fuel tanks. Manufactured by Omark Industries, the machine can accommodate airframe sections as much as ten feet wide and forty feet long. The N/C machine drills, countersinks, and installs sixteen rivets per minute. An N/C positioner rotates, elevates, and tilts a workpiece to the desired angle. The machine head clamps it, drills, and countersinks the proper size hole for a rivet stored in gravity hoppers. A rivet head then performs the riveting.[47]

An N/C shot-peening machine uses small hard steel shot hurled at high velocity to hammer the surface of a workpiece into compression and thereby increase its fatigue life. The Vacu-Blast Company manufactures a five-axis N/C shot-peening machine. It has twenty-five foot travel capacity along the X

axis, five feet along the Y axis, and 5½ feet along the Z axis. A boom on which the nozzle is mounted rotates 360 degrees while the nozzle itself moves 135 degrees. Various mechanical motions and the peening operation can be controlled automatically or manually by an operator at a control panel.[48]

A shearing machine controlled by N/C is manufactured by the Cincinnati Shaper Company. It is programmed by a computer which selects the best sequence and pattern to shear a given size sheet with the least amount of scrap. Computer output in punched card form is placed in the shear's card reader. Automatic control then provides for the positioning of front and back gauges, energizing probes, positioning of the delivery chute, and shear cycling.[49]

An N/C coil winding machine controls wire cutting, wire placement, cementing, loading, and ejection of an empty bobbin and finished coil. The MCU activates sequential or simultaneous functions and assures automatic timing, regulation of the number of turns, and control of motor speeds. Coils can be programmed and encoded on punched card and punched tape input media, for more turns at one end than the other and for midcoil taps.[50] A coil winding machine manufactured by the General Electric Company counts the number of turns per coil, indexes to the next coil, counts the number of indexes, and stops at the end of a cycle.

Inspection and Testing

Numerical control inspection and testing is a logical extension of N/C because it fulfills an increasing demand for improved accuracy, speed, and reliability in the inspection and testing of parts manufactured by N/C production equipment.[51] The criteria for inspection and testing with N/C are similar. In each situation, the machine is programmed to measure the variable under consideration and to display and/or record the data resolved from the measurements.

Inspection machines. Numerical control inspection is particularly advantageous where verification of the physical geometry of a workpiece is necessary or where measurement determination of the unknown geometry of a workpiece is required. An N/C inspection machine consists of a probe or sensing head, facilities for positioning and holding the workpiece to be measured, and a means of making and either displaying or recording the measurements made on the workpiece. These machines provide alignment along two horizontal axes and, in more sophisticated equipment, motions in the vertical axis as well as one or more axes of rotation or tilt.[52]

A representative N/C inspection machine is illustrated in Figure 26. This Lucas four-axis N/C inspection measuring machine was manufactured by the Lucas Machine Division of The New Britain Machine Company. It is equipped with a machine control unit which has built-in computer memory, permitting

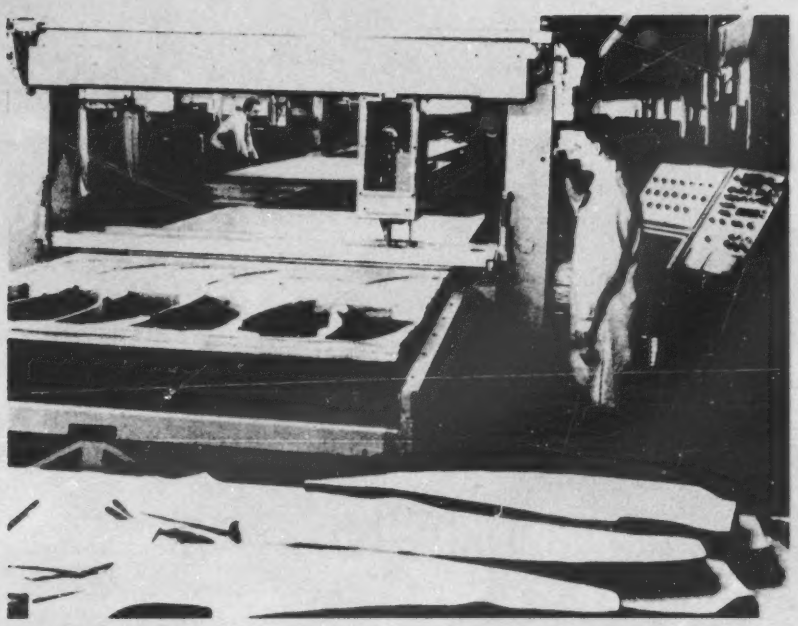

Figure 24. Fabric Cutting Machine (Courtesy of Cincinnati Milacron Company)

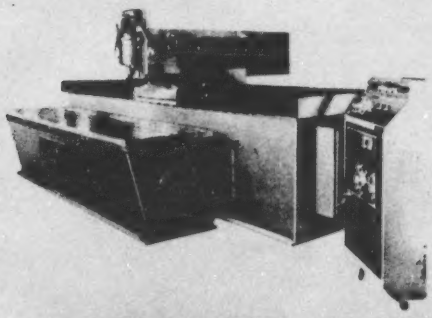

Figure 25. Woodworking Router (Courtesy of Ekstrom, Carlson, and Company)

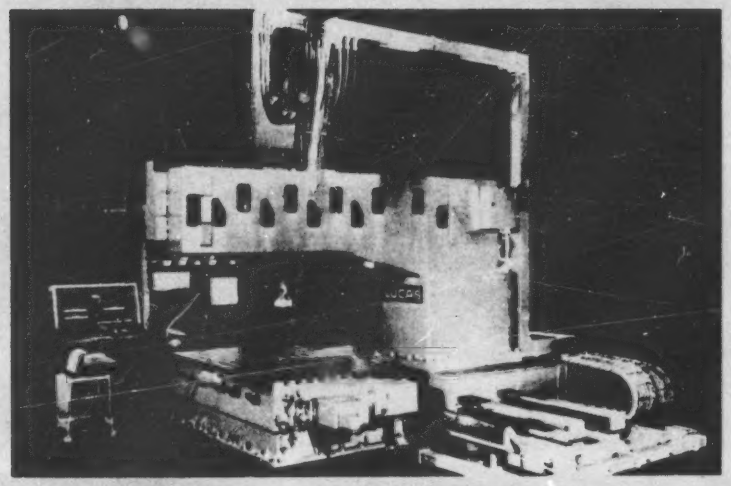

Figure 26. Inspection Machine (Courtesy of Lucas Machine Division of The New Britain Machine Company)

programmed patterns or routines to be stored and used on command. Among these routines is one for automatic hole finding with the aid of a probe. It has the ability to determine the center, diameter, and coordinate location of any hole in a workpiece, and to compare this information with input data. The machine is designed to perform automatic or semi-automatic measurements of the physical dimensions of a workpiece, and record this information on a typewritten hard copy printout and/or punched tape.[53] It is capable of measuring between any two points not over twelve inches apart on one axis, with an error of ±0.0005 inch and with repeatability of ±0.0001 inch. Inspection of a known three-dimensional workpiece is accomplished by programming two axes (either manual or punched tape input) and probing the third. Inspection of an unknown three-dimensional workpiece is accomplished by providing arbitrary coordinates in the non-probe axes and probing by means of manual input in the third axis. The machine has four axes of movement - vertical, transverse, longitudinal, and rotary. These axes are controlled by a closed loop electrohydraulic servo system.[54]

Testing machines. Numerical control is used to check printed circuit boards, as in the case of a pre-assembly testing operation. An N/C system requires only that a board be plugged into a module check unit. The appropriate test(s) and limits are programmed and coded on punched tape, which then directs the test activity.[55]

An example of a testing machine under numerical control is a device manufactured by the Bunker-Ramo Corporation. This machine is used for inspecting printed circuit boards before they are installed in machine control units. The testing machine has a four bank console which cycles through tests under the control of punched tape input. The console makes as many as 1500 different tests on a printed circuit board, in fifteen minutes. The machine goes through its testing sequence until it discovers a failure, whereupon the operator activates a repeat switch to rerun the test. Repairs can be made at this time or testing can continue with repairs to be made later. This system detects incorrect components, shorts and opens, and wiring faults in seconds. It has available supplementary testing instruments for complete analysis of any fault discovered.[56]

SECTION III

SUMMARY

This paper presents a description of N/C operational devices. Operational devices identified and described under the classification of design and drafting include N/C drafting machines and N/C plotting machines. These machines are used for the preparation of drawings from mathematical descriptions, verification of tool and cutter path data on machine control input media, contour mapping, layout of printed circuit artwork masters and inspection templates, architectural drafting, and automatic drafting of complex three-dimensional shapes.

Operational devices identified and described under the classification of production equipment include numerically controlled drilling, milling, boring, turning, grinding, punching and notching, tube bending, flame cutting, welding, filament winding, component insertion, wire processing, and fabric cutting machines, as well as machining centers, routers and shapers. Miscellaneous production equipment applications include screwdrivers, riveting, shot-peening, and shearing machines. As the number of applications under the classification indicates, numerical control has been adopted extensively for use by production equipment.

Operational devices identified and described under

the classification of inspection and testing include N/C inspection and N/C testing machines. These machines are a logical extension of N/C because they fulfill an increasing demand for improved accuracy, speed, and reliability in the inspection and testing of parts manufactured by N/C production equipment.

FOOTNOTES

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